RF IMPEDANCE SENSING OF MOISTURE CONTENT IN INDIVIDUAL DATES

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ABSTRACT. *Measurements of the impedance at 1 and 5 MHz of a parallel-plate electrode assembly with individual dates between the electrodes predicted date flesh moisture content with a standard error of about 1% moisture content (m.c.) over the range from 13 to 22%. The predictions on California Deglet Noor dates from the 1990 crop were based on a calibration equation developed previously on dates from the 1988 and 1989 crops. Combining data on dates of 12% m.c. or higher from all three crop years provided a new calibration, which permits computation of m.c. from measurements of capacitance only at the two frequencies. The instantaneous, nondestructive m.c. sensing technique is recommended for further development for on-line sorting to reduce the skilled-labor requirements in the sorting and grading of fresh dates.*
Keywords. *Radio frequency, Impedance, Capacitance, Moisture content, Dates.*

As with most agricultural products, moisture content of dates (fruit of the date palm, *Phoenix dactylifera* L.), is a very important characteristic. At harvest, bunches of dates from the tree contain dates of widely ranging moisture content, and they need to be sorted promptly so that those of high moisture can be dried for safekeeping. Although moisture content is not a specific factor in the grading of dates, the different grades are highly correlated with date flesh moisture content.

Dates are generally sorted by hand into marketable and product grades. The marketable dates are judged suitable for packaging as whole or pitted dates. Product grades are exported or used for diced or ground date products. Official USDA grades are determined subjectively based on color, uniformity of size, absence of defects, and character (USDA, 1955). Character, which accounts for 40% of the evaluation, involves subjective determination of development, ripening, and moisture content. The USDA standards define six grades: A, B, B (Dry), C, C (Dry), and Substandard; the first five of which have alternate designations of U.S. Fancy, U.S. Choice, U.S. Choice (Dry), U.S. Standard, and U.S. Standard (Dry), respectively.

The U.S. date industry uses four grades for marketing (Chesson et al., 1979): Natural, Waxy, No. 1 Dry, and No. 2 Dry, in order of decreasing moisture content from about 23%* or higher to less than 15%. No. 2 Dry dates must be rehydrated to moisture contents above 15% for marketing as fresh fruit. At harvest, dates may range in moisture content from about 12 to 30% (Davies, 1991). These dates grade all the way from Naturals that need to be dried for safe storage if moisture content is higher than about 23% to No. 2 Dry. Therefore, they must be sorted to separate those that need to be dried before they can be safely stored. The desirable moisture content for the widely grown Deglet Noor cultivar in California was reported to be 23 to 25% (Rygg, 1975; Nixon and Carpenter, 1978). At higher moisture contents, the dates are subject to molding and fermentation. More recent experience, using moisture contents determined by the Dried Fruit Moisture Tester (Type A Series, Dried Fruit Association (DFA) of California, P. O. Box 270A, Santa Clara, CA 95052) places that desirable moisture range for Deglet Noor dates generally at 20 to 22%, although the allowable range varies significantly with growing conditions and the quality of the crop from year to year (Davies, 1992).

The importance of moisture content in determining the permissible length of storage has been reviewed recently (Nelson and Lawrence, 1992). Shelf life can be extended by storage at lower temperatures, but, in general, deterioration (darkening and loss of flavor) increases with increasing moisture content.

Hand sorters use at least three criteria in making grade determinations elasticity (by feel), surface texture, and color (Chesson et al., 1979). In most packing houses, dates are hand sorted and graded as they move along on conveyors or oscillating tables. Although dates cannot be graded on the basis of moisture content alone, automatic sensing of individual dates for moisture content would be useful in separating high-moisture dates at harvest from those that do not require drying. It could also be used to separate the drier dates from those that require careful grading and thus reduce the quantity of material to be manually graded into marketable and product grades. Therefore, a practical rapid moisture sensor for individual fruit could reduce the amount of skilled labor required to

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* Moisture contents throughout this article are expressed in percent, wet basis.

sort and grade dates, thus being of significant benefit in this highly labor-intensive industry.

Date moisture determination methods were also reviewed recently (Nelson and Lawrence, 1992). When moisture contents are measured in the U.S. date industry today, most frequently the practical measurements are taken with an electrical resistance-type meter designed for the dried fruit industry (DFA moisture tester) that has been calibrated against vacuum oven moisture determinations. Different oven temperatures and times for drying have been reported in the literature. The Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC, 1984) includes a vacuum oven method for dried fruits and the DFA Moisture Meter method for prunes and raisins. The vacuum oven method specifies drying 5 to 10 g of ground or finely chopped sample for 6 h at 70° C under a vacuum of at least 100 mm Hg with a slow current of air admitted after passing through H_2SO_4 for removal of moisture. For raisins and other fruit rich in sugar, a sample size of 5 g, mixed with 2 g of finely divided asbestos and especially prepared before vacuum drying, is specified.

Because vacuum oven methods are slow and tedious, and because the electrical meter methods still require grinding and are more suited to the laboratory, there is interest in a more rapid and less troublesome technique for moisture determination. Because of obvious needs for on-line moisture sensing, work was initiated on ways to instantaneously sense the moisture content of whole individual dates nondestructively (Nelson and Lawrence, 1992). With laboratory equipment, radio-frequency (RF) impedance measurements at two frequencies, 1 and 5 MHz, on a parallel-plate capacitor holding a single date between the plates, were used to estimate moisture content of whole and pitted dates with standard errors of about 1% moisture content. A calibration was established, and verification measurements on dates from the subsequent crop year were completed. This article summarizes the results of these measurements and justifies further exploration of this technique for potential development for alleviation of the skilled-labor requirements in sorting and grading dates.

Methods and Materials

Fruit

Dates for the studies were grown in the Coachella Valley of California in 1990 and shipped to Athens, Georgia, in February, 1991, where they were stored at 4° C until samples were selected for these studies. The dates were all of the Deglet Noor cultivar, of Natural, Waxy, No. 1 Dry, and No. 2 Dry grades, ranging between 9 and 22% in m.c. Samples were removed from refrigerated storage and kept overnight in sealed containers at 24° C before measurement.

The same procedures developed previously for practical vacuum-oven moisture tests of dates were used (Nelson and Lawrence, 1992). The date was slit longitudinally and the pit was removed. The date flesh was then chopped with a knife on a ceramic plate into pieces of about 3-mm maximum dimensions. The chopped flesh of the entire date, about 5 g, was placed in a disposable 57-mm aluminum weighing dish and spread out for drying. When date moisture content was too high for chopping into pieces, the date paste was spread in a thin layer over the bottom and sides of the aluminum weighing dish. Samples were dried in the aluminum weighing dishes for 48 h in a GCA/Precision Scientific Cat. No. 31468 Thelco vacuum oven at 70° C. Air admitted to the oven passed through a drying column of anhydrous $CaSO_4$ (Drierite with indicator), and dry air flow during the drying period was adjusted to maintain a vacuum of about 600 mm Hg. Samples were cooled in a desiccator over anhydrous $CaSO_4$ before being reweighed at the end of the tests. The moisture content was calculated on a wet basis.

Electrical Measurements

The impedance measurements were taken with the dates between plane parallel-plate electrodes of circular shape and 5 cm diameter. The measurements were taken on individual whole dates and on the same dates again after the pit had been removed and the date closed. The parallel-plate electrode assembly described previously (Nelson and Lawrence, 1992) was connected to a Hewlett-Packard 4192A LF Impedance Analyzer through a 16096A Test Fixture. Impedance measurements were taken at 1 and 5 MHz with the impedance analyzer, controlled by an IBM XT computer, in the parallel-circuit mode (fig. 1). In this mode, the impedance analyzer measures conductance $G = 1/R$, where R is resistance, and susceptance $B = \omega C$ and calculates values for the admittance magnitude $|Y| = \sqrt{G^2+B^2}$ and phase angle $\theta = \tan^{-1}(\omega CR) = \tan^{-1}(B/G)$, as well as capacitance C and dissipation factor $D = \tan\delta = 1/(\omega CR) = G/(\omega C) = G/B$, where δ is the loss angle (the complement of the phase angle θ between voltage and current in the parallel-equivalent circuit), and ω is the angular frequency, $2\pi f$, where f is the frequency of the applied signal.

Procedures

Initial weights of the dates and weight data for the date moisture tests were obtained during the RF impedance measurement sequence. These data were obtained with a Mettler AE 163 electronic balance interfaced to the computer. At the beginning of the measurement sequence, the whole date was weighed to the nearest 0.1 mg. Then the date was placed between the parallel-plate electrodes, the impedance measurements were obtained by the impedance analyzer, and the data were stored in the computer. Next, an aluminum dish was weighed, the date was slit, and the pit was removed. The pitted date was closed and placed between the parallel-plate electrodes, and the impedance measurements were taken on the pitted date. The date flesh was chopped and placed into the

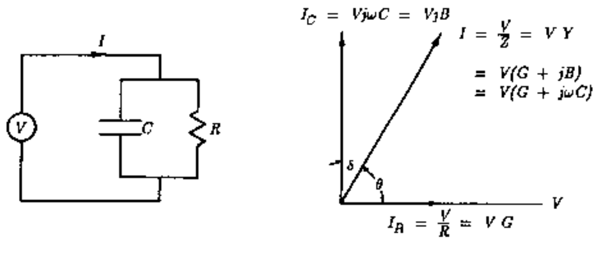

Figure 1–The RC parallel-circuit representation and associated phasor diagram.

aluminum dish, and the weight of the dish and flesh sample was taken. The sequence was repeated until data had been collected for 18 dates of each of 5 different moisture groups. The sample size was selected on the basis of vacuum oven capacity for the moisture tests (three shelves and 18 moisture dishes per shelf). Moisture dish locations were randomized within the oven for samples of different moisture levels. Moisture contents were calculated by the computer as samples were weighed at the end of the moisture tests.

Computation of Moisture Content

The moisture content of the individual dates, as determined by the dual-frequency impedance measurements, was then calculated from the originally determined calibration equations reported previously (Nelson and Lawrence, 1992):

Whole dates: $M = 16.997 + 3.324 \ln \Delta C \quad r^2 = 0.9454$ (1)

Pitted dates: $M = 16.507 + 3.118 \ln \Delta C \quad r^2 = 0.9402$ (2)

where $\Delta C = C_1 - C_5$, the difference between the capacitance values measured at 1 and 5 MHz, respectively. Two additional calibration equations were presented (Nelson and Lawrence, 1992) which involved two variables and provided slightly higher coefficients of determination, r^2 values:

Whole dates:
$M = 17.617 + 3.051 \ln \Delta C - 0.000464[1/(\Delta G \Delta B)]$
$r^2 = 0.9590$ (3)

Pitted dates:
$M = 18.195 + 13.929\, \Delta B + 3.822 \ln \Delta C$
$r^2 = 0.9536$ (4)

The single-variable model was chosen in view of the minor improvement in the r^2 value and the simplicity of a capacitance measurement compared to a complex impedance measurement required for the two-variable model.

Results and Discussion

Typical moisture contents predicted by the dual-frequency impedance measurements are shown in table 1 for the 1990 dates with moisture content in the valid calibration range (13 to 30% moisture). Twelve of the 90 dates tested less than 13.0% moisture content (m.c.) and had to be excluded. Values of moisture content determined from the impedance measurements and calculated according to equations 1 to 4 are compared directly with the vacuum-oven moisture determinations in table 1 where comparisons, including differences between predicted and vacuum-oven moisture determinations, are shown for the lowest, highest, and every sixth intervening moisture content. The mean values of the differences between predicted and oven moisture values over all 78 dates are shown as the bias for each measurement. The standard deviation of the differences between the calculated moisture content and the vacuum-oven moisture value are also shown as the standard error of performance

Table 1. Moisture contents in percent, wet basis, of whole and pitted dates, as predicted by RF impedance measurements with single-variable and two-variable linear regression models, compared with vacuum oven moisture content determinations

Vacuum	Single-variable Model				Two-variable Model			
Oven	Whole Dates		Pitted Dates		Whole Dates		Pitted Dates	
m.c.	m.c.	Diff.	m.c.	Diff.	m.c.	Diff.	m.c.	Diff.
13.0	14.4	1.4	14.3	1.3	14.5	1.5	14.1	1.1
13.7	15.1	1.4	13.0	−0.7	15.4	1.7	12.8	−0.9
14.0	14.3	0.3	15.4	1.4	14.3	0.3	15.4	1.4
14.3	12.2	−2.1	14.9	0.6	10.4	−3.9	14.8	0.5
14.6	12.8	−1.8	15.3	0.7	12.1	−2.5	15.0	0.4
15.1	14.9	−0.2	15.5	0.4	15.1	0.0	15.4	0.3
15.7	15.2	−0.5	16.0	0.3	15.3	−0.4	15.7	0.0
16.2	16.2	0.0	17.0	0.8	16.5	0.3	16.9	0.7
17.5	16.2	−1.3	18.8	1.3	16.3	−1.2	18.4	0.9
18.2	19.4	1.2	18.7	0.5	19.7	1.5	18.2	0.0
18.9	17.6	−1.3	19.1	0.2	17.8	−1.1	19.3	0.4
19.7	19.3	−0.4	19.8	0.1	19.6	−0.1	19.5	−0.2
20.5	19.8	−0.7	19.9	0.6	20.1	−0.4	19.5	−1.0
22.4	21.7	−0.7	21.3	−1.1	21.9	0.5	20.4	−2.0
Bias (mean diff.):		−0.01		0.58		0.12		0.32
SEP:		0.91		0.76		1.07		0.86

NOTE: Lowest, highest, and every sixth intervening moisture content for 78 dates shown. Bias and standard error of performance (SEP) shown for measurements on all 78 dates.

(SEP)‡ value. For the single-variable model, the SEP values for whole and pitted dates are 0.91% m.c. and 1.16% m.c., respectively. These values may be compared with the standard error of calibration (SEC)§ values of 0.99% m.c. and 1.16% m.c. for whole and pitted dates, respectively, obtained when calibrating the system with 1988 and 1989 dates (Nelson and Lawrence, 1992). Graphical representation of the verification data is presented in figures 2 and 3 for whole dates and pitted dates, respectively. The greater bias of the pitted-date moisture data (0.58% m.c.) is evident in figure 3 when compared with that of the whole-date data in figure 2.

The single-variable model, equations 1 and 2, provided slightly lower standard errors of performance (table 1) than the two-variable model for both the whole dates and the pitted dates in this instance. The bias of the moisture measurement by the impedance technique was less for the pitted dates when the two-variable model was used. The bias for both models was of no real consequence with either model for the whole dates. So, on the basis of the original calibration on 1988 and 1989 dates and the verification tests on lots from the 1990 crop, the single-variable model, involving only capacitance measurements, appears to be adequate for estimating individual date moisture contents with a standard error of about 1% m.c.

‡ $SEP = \left[\frac{1}{n-1}\sum_{i=1}^{n}(e_i - \bar{e})^2\right]^{1/2}$ where n is the number of observations, e_i is the difference in the m.c.predicted and that determined by the reference method for the *ith* sample, and $\bar{e}$ is the mean of e_i for all of the samples.

§ $SEC = \left[\frac{1}{n-p-1}\sum_{i=1}^{n} e_i^2\right]^{1/2}$ where n is the number of observations, p is the number of variables in the regression equation with which the calibration is performed, and e_i is the difference between the observed and reference value for the *ith* observation.

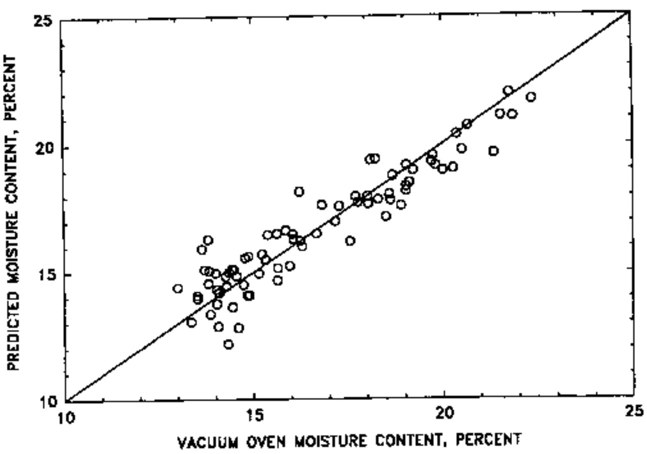

Figure 2–Prediction of date flesh moisture content from RF impedance measurements on whole dates in parallel-plate capacitor according to single-variable linear model, equation 1.

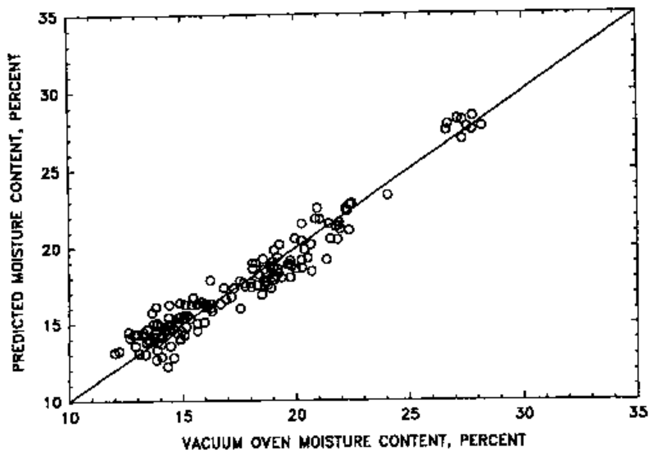

Figure 4–Single-variable model calibration data for Deglet Noor date flesh moisture content from RF impedance measurements on whole dates in parallel-plate capacitor, equation 5.

Using this same model, we took the data from the original calibration set on 1988 and 1989 dates and that of the verification set on 1990 dates of 12% moisture or more and combined them to provide a new calibration equation as follows:

Whole dates: $M = 16.732 + 3.106 \ln \Delta C \quad r^2 = 0.939 \quad (5)$

Pitted dates: $M = 15.883 + 3.027 \ln \Delta C \quad r^2 = 0.944 \quad (6)$

The SEC for whole dates was 0.908% m.c. and that for the pitted dates was 0.870% m.c.

The new calibration equations 5 and 6 are expected to be somewhat more representative for dates of the Deglet Noor cultivar, since more samples and an additional crop year were represented in the calibration data. The data involved in this calibration are shown in figures 4 and 5 for whole and pitted dates, respectively.

The utility of the dual-frequency, parallel-plate capacitance measurement for separating individual dates according to moisture content, with a standard error of about 1% m.c. has been established in principle. The problems of implementing such a measurement system for practical on-line sorting of dates have not been addressed. Development of relatively inexpensive capacitance measuring instruments suitable for this application should be feasible. The problem of periodic automatic cleaning of the parallel-plate electrodes would probably have to be considered as an essential feature of a successful on-line sorting system. A study of the savings that might be achieved by the development and installation of instrumentation and sorting systems based on these principles would be required to determine the justification for the further research and development needed to achieve a practical on-line sorting system.

CONCLUSIONS

Previously developed calibration equations for estimating moisture content of individual whole dates and pitted dates, based on impedance measurements at 1 and 5 MHz on Deglet Noor dates from the 1988 and 1989 California crops, estimated moisture content of 1990 dates of the same cultivar from the same source with standard errors of comparable magnitude, about 1% m.c. The original calibration data combined with the new

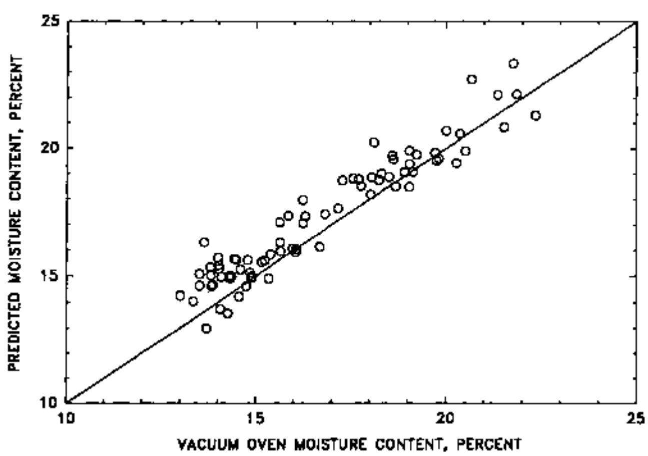

Figure 3–Prediction of date flesh moisture content from RF impedance measurements on pitted dates in parallel-plate capacitor according to single-variable linear model, equation 2.

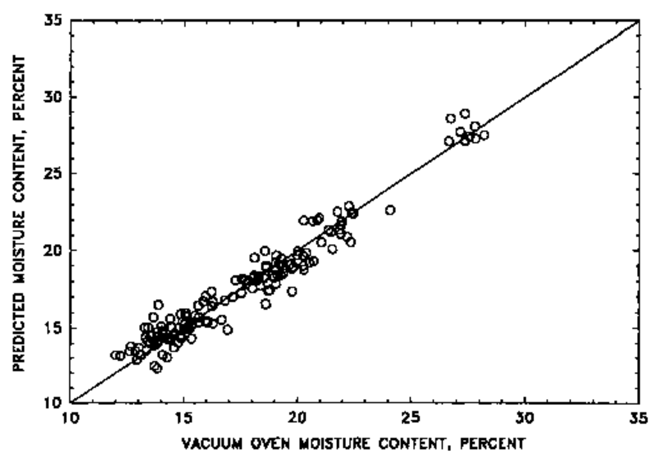

Figure 5–Single-variable model calibration data for Deglet Noor date flesh moisture content from RF impedance measurements on pitted dates in parallel-plate capacitor, equation 6.

verification data on dates from the 1990 crop provide a new calibration equation more representative of California dates of the Deglet Noor cultivar for the moisture content range from 12 to 28%. The equation, based on a single variable model, requires only capacitance measurements at 1 and 5 MHz on the parallel-plate electrode assembly. The accuracy and simplicity of this instantaneous, nondestructive measurement justify further exploration of this technique for potential application in the automatic sorting of dates to reduce the skilled-labor requirements in manual date sorting and grading processes.

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